REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE Viewgraphs	3. DATES COVERED
4. TITLE AND SUBTITLE NDE R&D at NAWC		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Ignacio Perez		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Ignacio Perez
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	41	(301) 342-8074

Standard Form 298 (Rev. 8-98)
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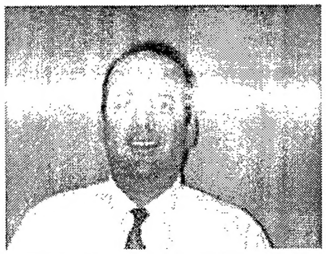
NDE R&D at NAWC

Naval Air Warfare Center, Aircraft Division
Patuxent River, MD
October 16, 2000

Team



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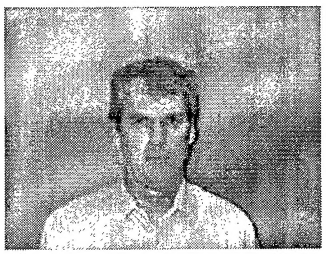
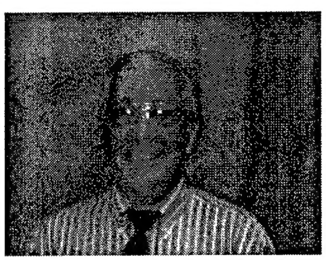


JL

RS



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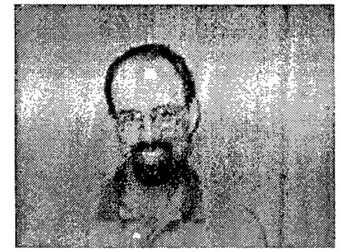
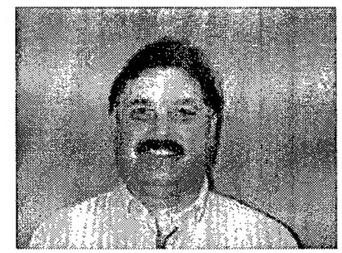


RP



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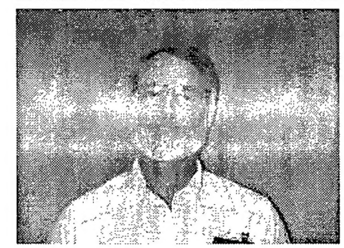

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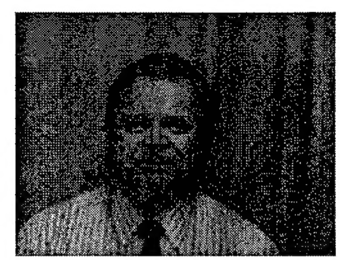
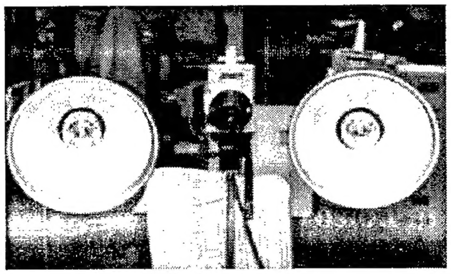


R&D

Thermography

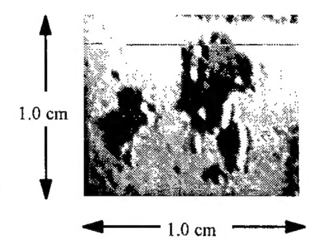


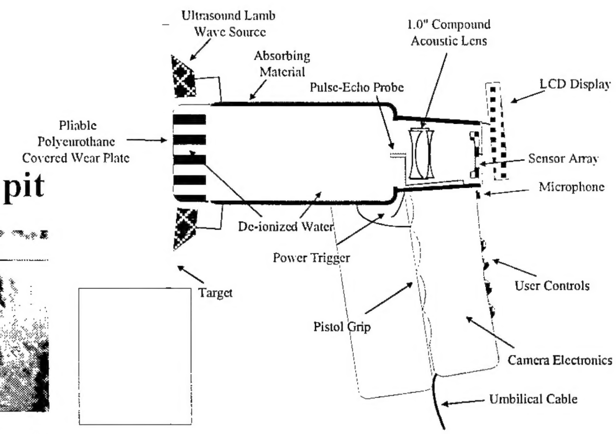
- •Non-Contact
- •Wide Area
- •Fast
- •Cuverd Surfaces

- •Corrosion
- •Impact Damage
- •Delamination
- •Water Intrusion

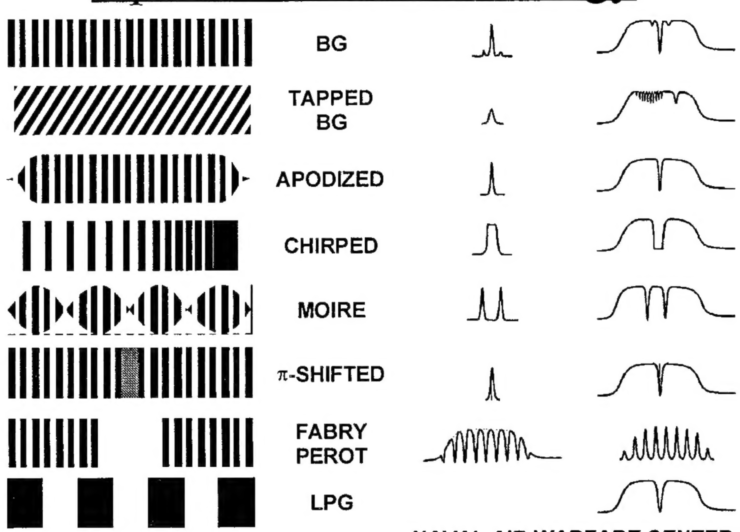
Ultrasonic Imaging

Corrosion pit

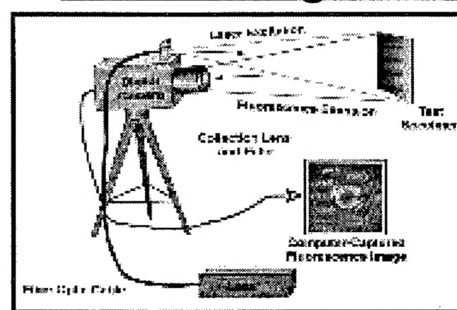


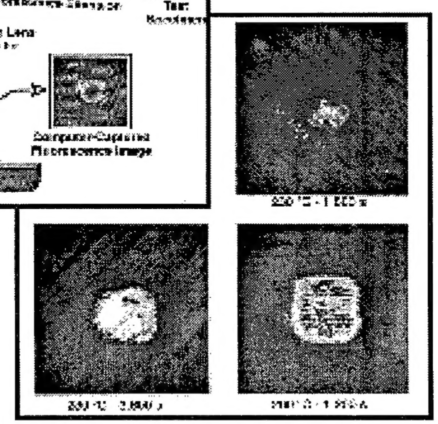


Optical Fiber Technology



Heat Damage Detection - LPF





NAVAL AIR WARFARE CENTER, AIRCRAFT DIVISION, PAUXENT RIVER, MD

TEAM

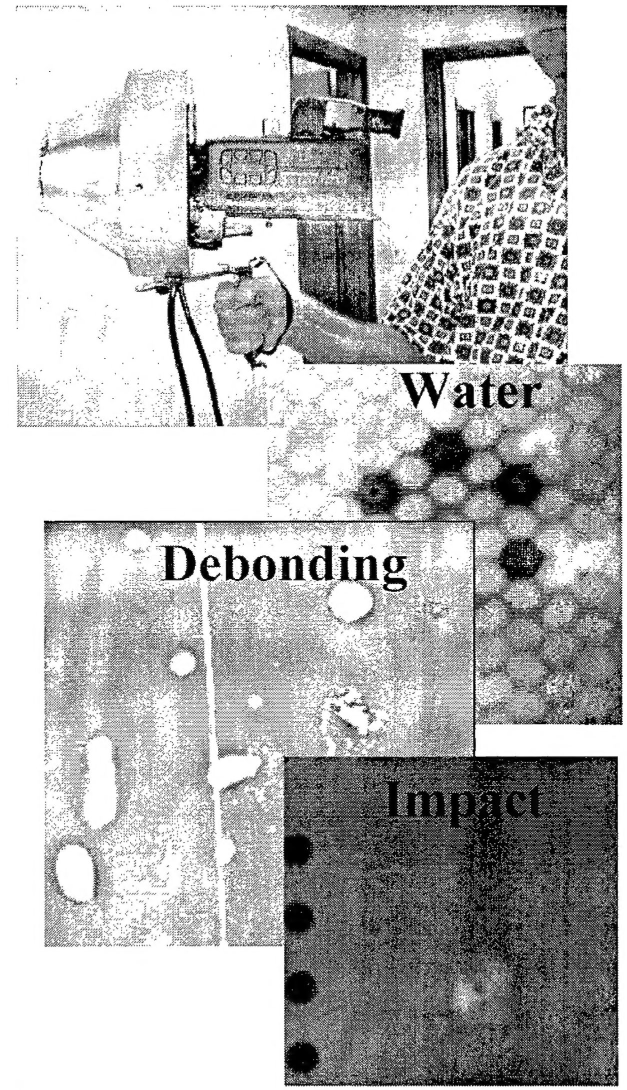
RESEARCH & ENGINEERING

Thermography

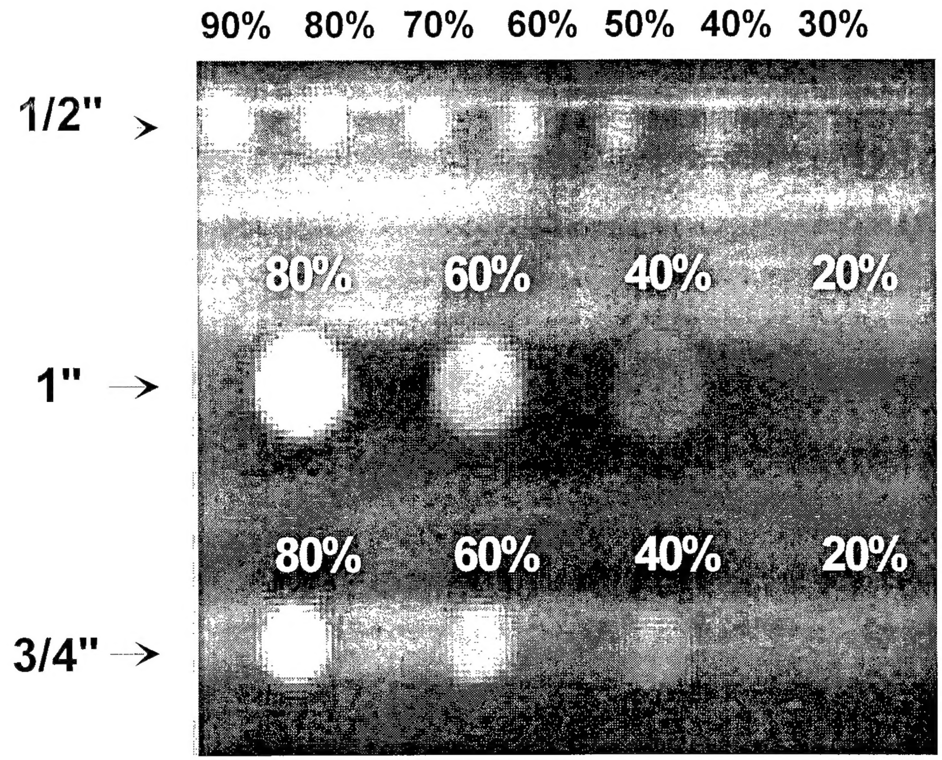
INFRARED THERMOGRAPHY

- Problem: **Rapid and reliable detection of hidden corrosion, impact damage, water entrapment.** Solution: **Development and Transition Infrared Thermography to I- and D- level maintenance programs**
- Advantages (compared to ultrasonic inspection):
  - NO COUPLANT REQUIRED
  - WIDE AREA INSPECTION METHOD
  - INSENSITIVE TO CURVATURE
  - EASY TO INTERPRET
  - PORTABLE
  - NO SAFETY REQUIREMENTS.
- Cost Savings:
  - 30 ft^2/min INSPECTION RATE (COMPARED TO 1 ft^2/min FOR UT
  - CAN DETECT CORROSION WITH OUT PAINT REMOVAL
  - (DOES NOT GENERATE WASTE PRODUCTS)
  - CAN DETECT CORROSION INSIDE LAP JOINT
  - $ 25M/Aircraft POTENTIAL COST SAVINGS FOR F-18 E/F OVER THE LIFE OF THE AIRCRAFT (Boeing Data)
- Transition Potential: **P-3C, C-130, KC-135, F-18 C/D, JSF**

HAND-HELD PROTOTYPE IR NDT SYSTEM

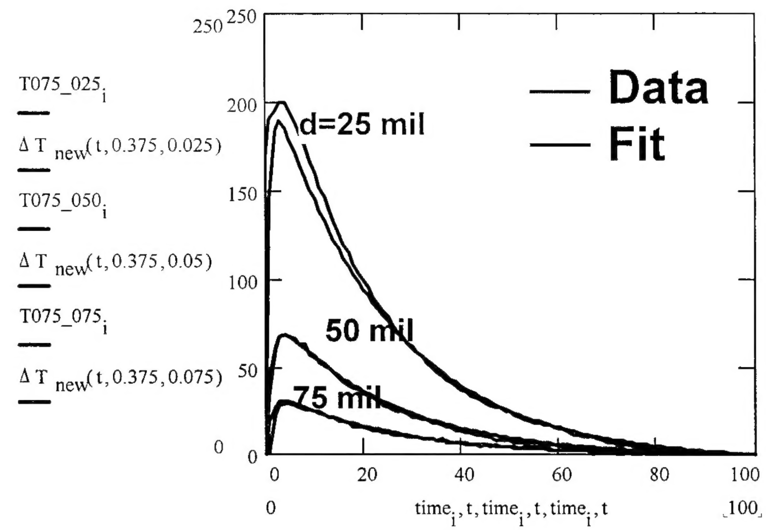


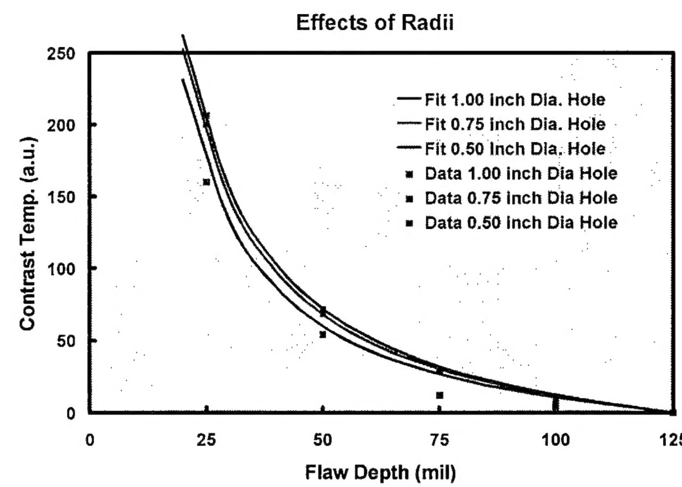
Thermographic Modeling



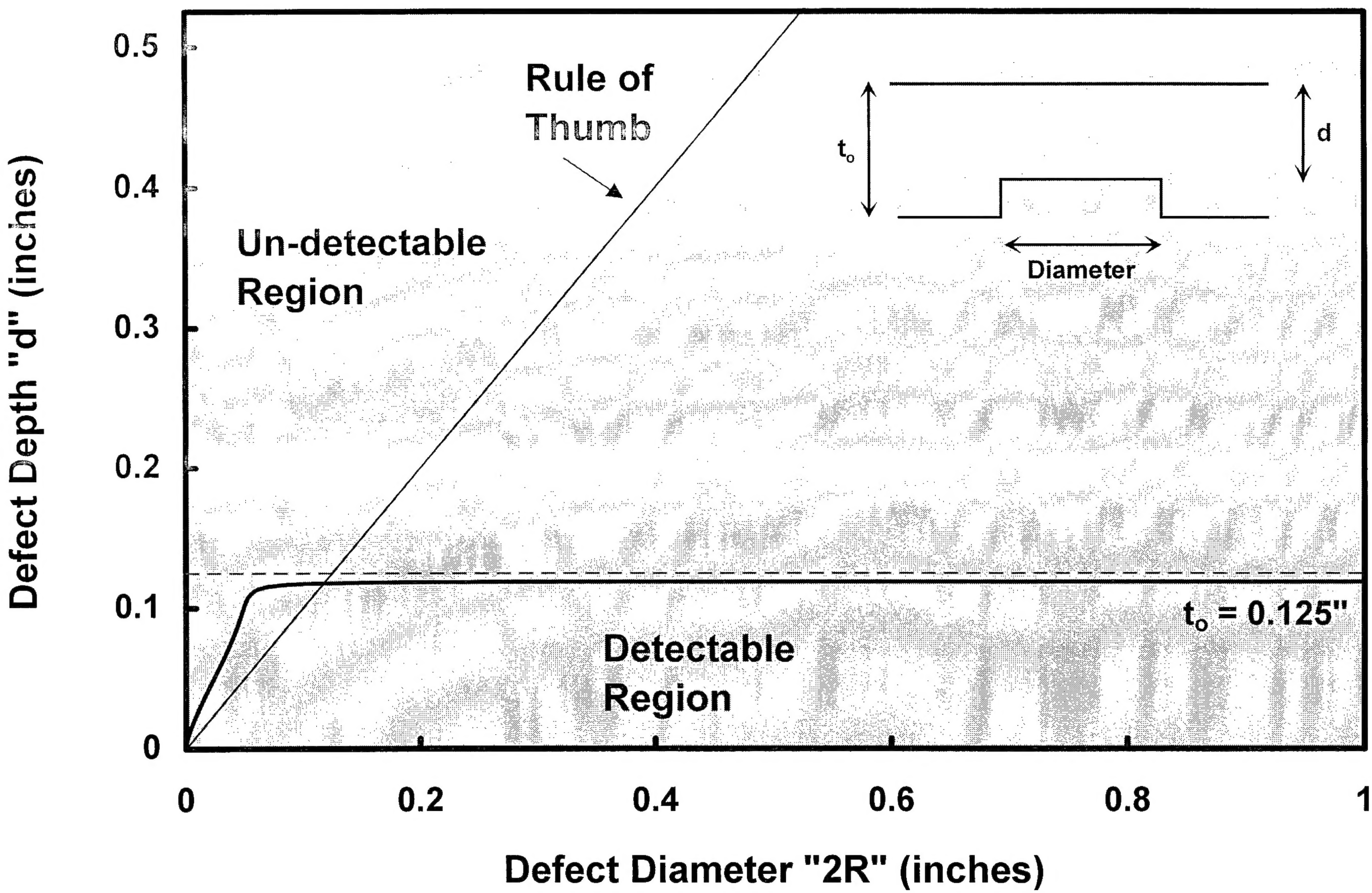
$$\Delta T_{front}(t) = \frac{Q}{\rho c} \cdot \frac{e^{-2\frac{k_L \cdot t}{\rho c \cdot R^2}} - e^{-\frac{k_n \cdot t}{2\rho c}\left(\frac{t_o}{d \cdot (t_o - d)}\right)^2}}{d \cdot \left(1 - \frac{4 \cdot d^2 \cdot (t_o - d)}{R^2 \cdot t_o} \frac{k_L}{k_n} + \frac{d}{t_o - d}\right)}$$

Dia = 0.75"





Depth of Resolution



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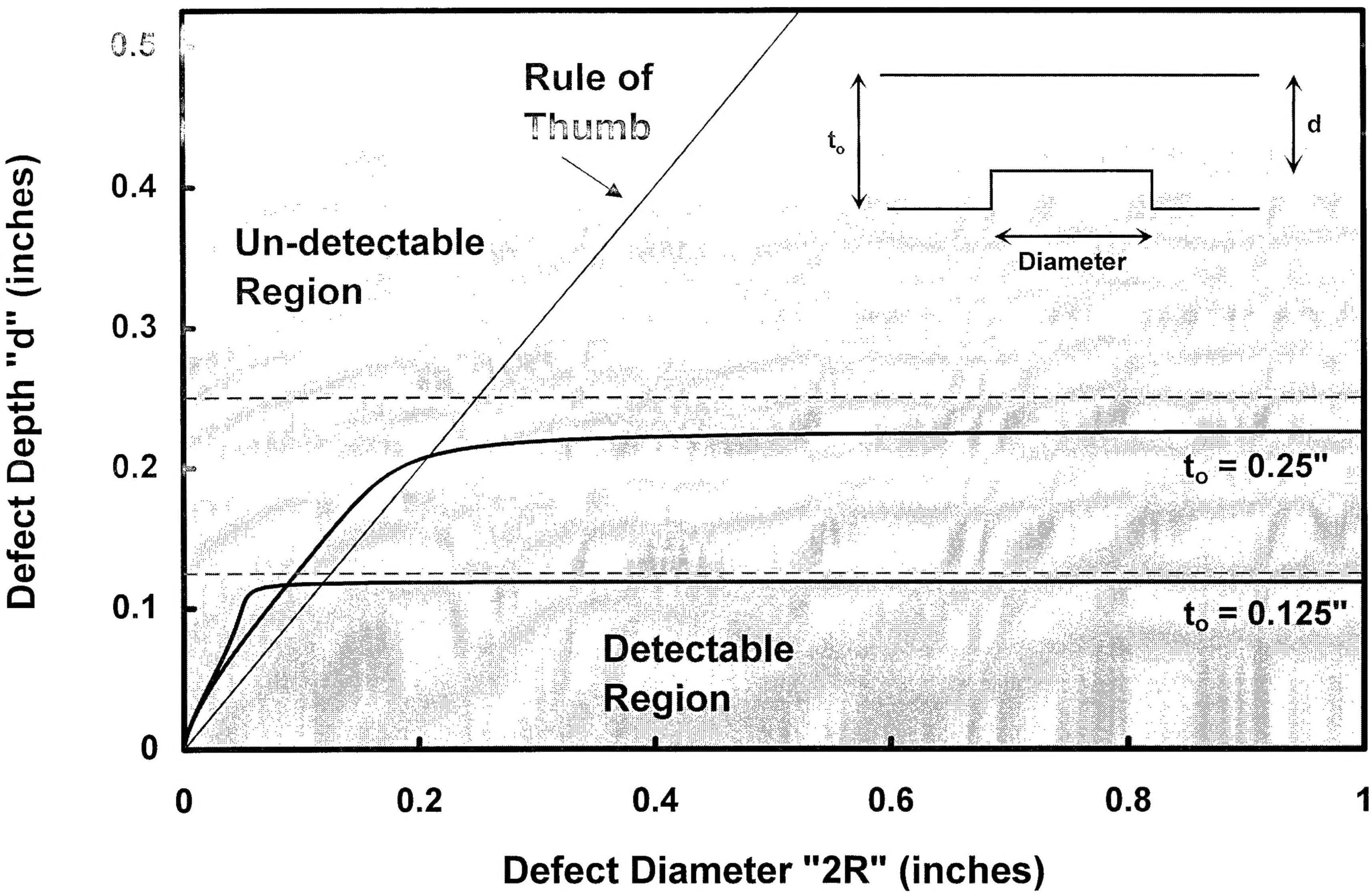
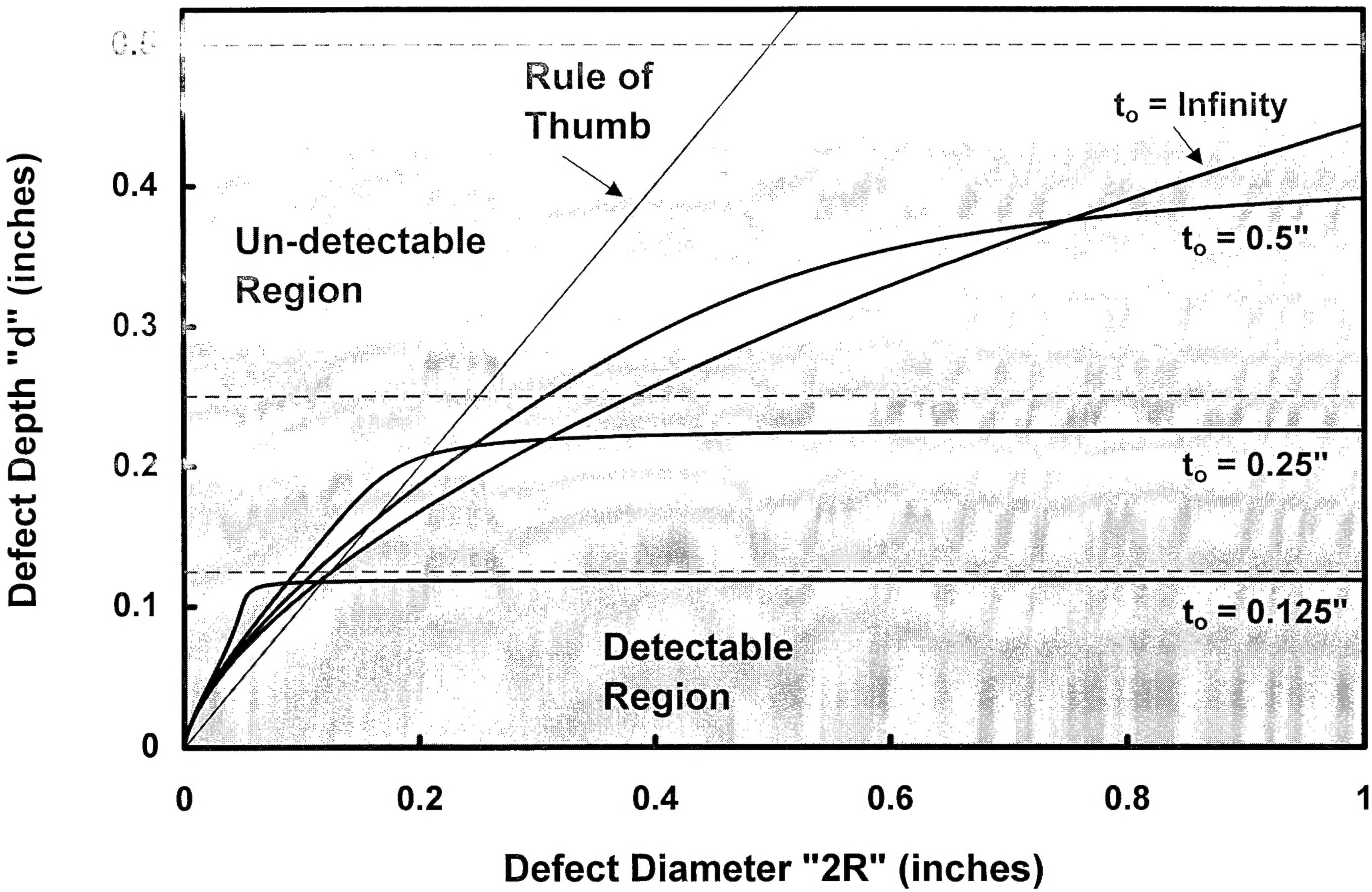


Depth of Resolution



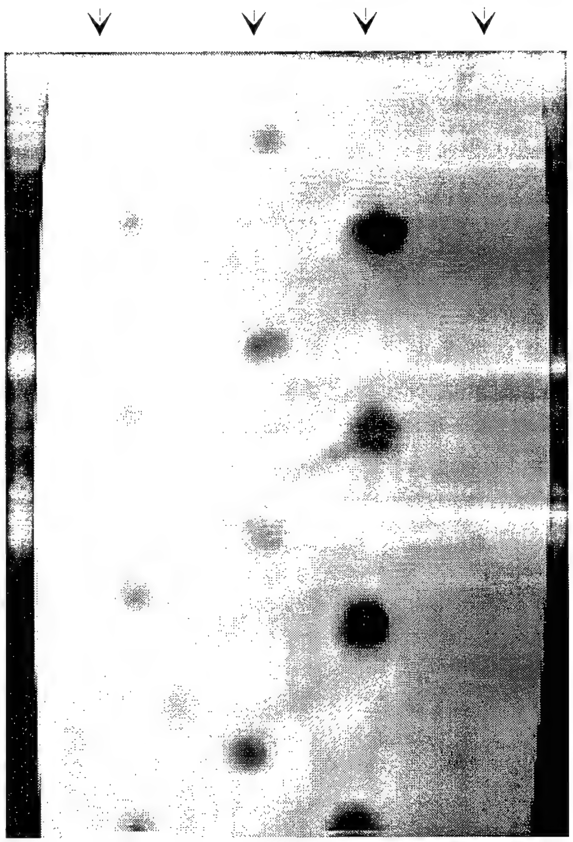
Thermography

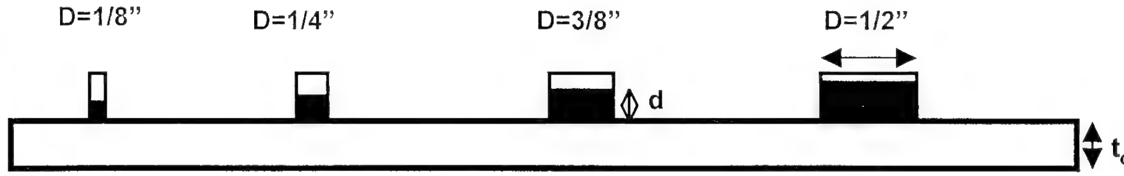
Water Entrapment

- Water entrapment is a major cause of material degradation.
- In metals it leads to corrosion.
- In honeycomb structures it can lead to face sheet separation during freezing
- In bonded structures is a primary mechanism for bond degradation
- In composites it adds unnecessary weight to the structure and can lead to material degradation especially after freezing and thawing.

SAMPLES PREPARATION

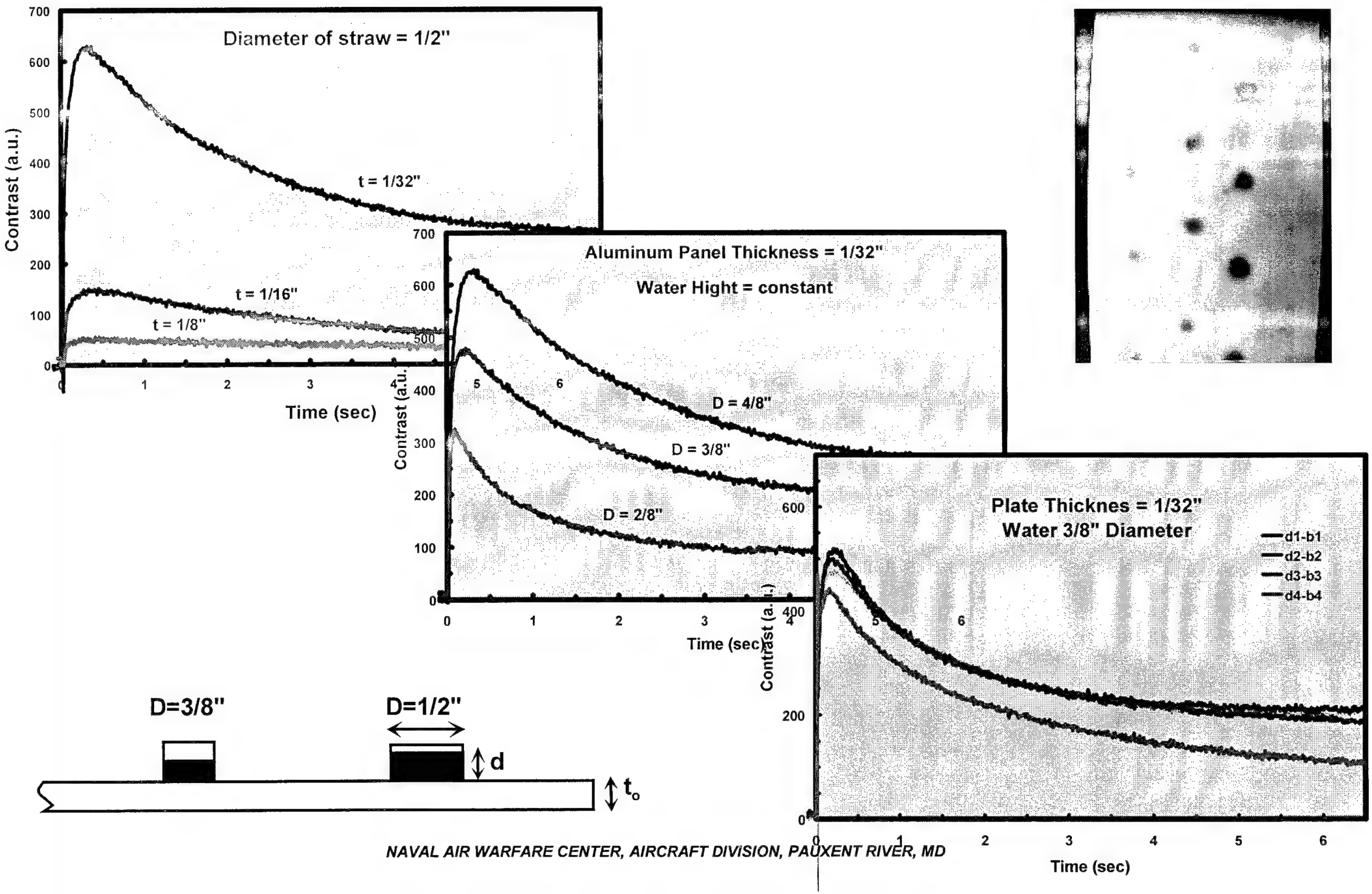
R = 1/4" 3/8" 1/2" 1/8"



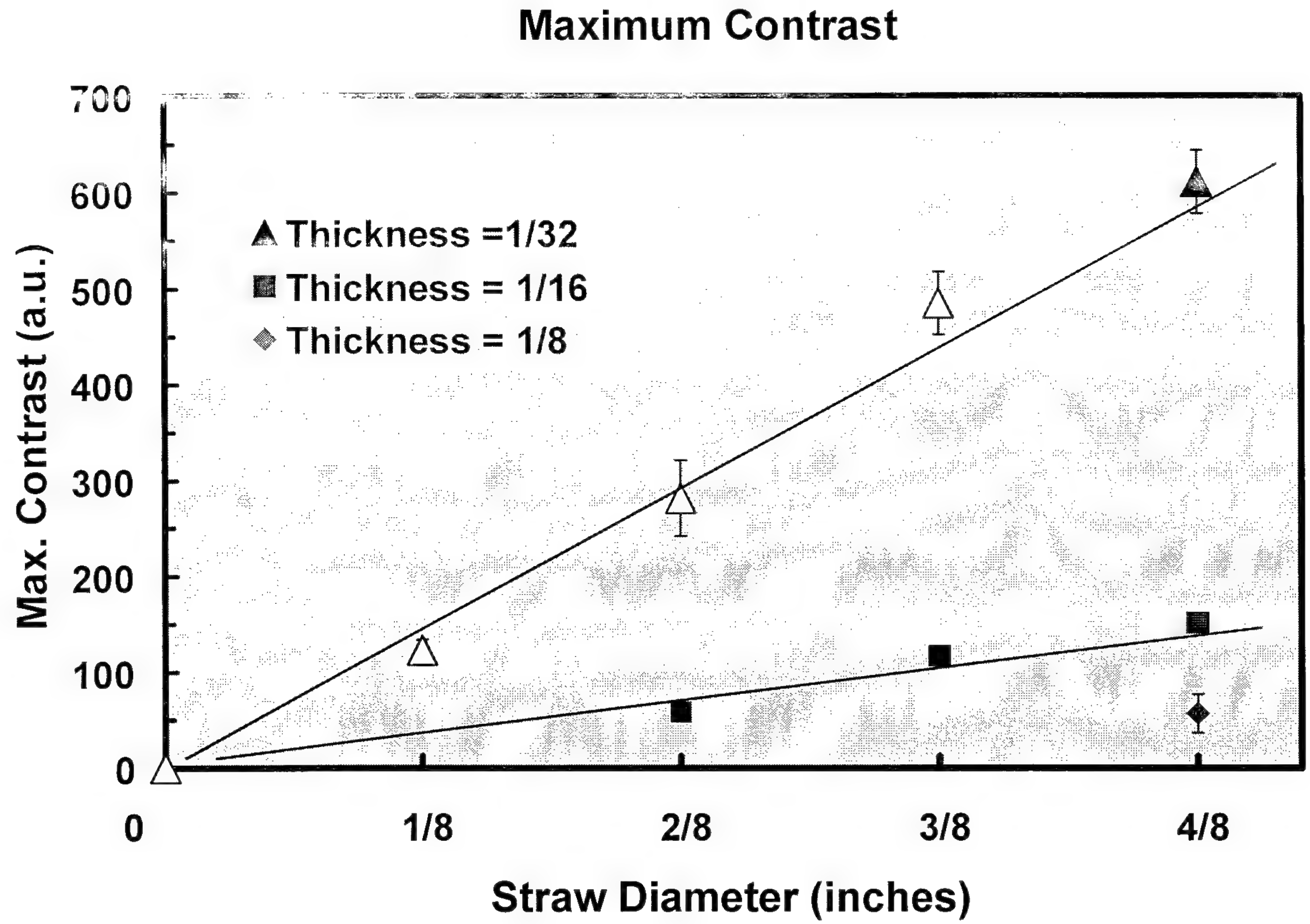


Experimental Parameters for Drops and Panels		
Al Thickness	Straw Diameter	Water Height
t_o = 1/32"	D = 1/8"	d = 0"
t_o = 1/16"	D = 1/4"	d = 1/16"
t_o = 1/8"	D = 3/8"	d = 1/8"
	D = 1/2"	d = 3/16"
		d = 1/4"

Experimental Data



Experimental Data II



- The thinner the aluminum substrate the larger the contrast
- The smaller the straw diameter the smaller the contrast
- The amount of water in the straw does not affect the contrast (error bars small)

LATERAL HEAT FLOW EFFECTS
(effective contact conductivity model)

Contrast curve

$$\Delta T(t) = \frac{Q}{\rho_1 c_1 \cdot t_o \cdot \sqrt{(1+a+r)^2 - 4ar}} \left(e^{\frac{h}{\rho_1 c_1} \frac{\lambda_3}{t_o} t} - e^{\frac{h}{\rho_1 c_1} \frac{\lambda_2}{t_o} t} \right)$$

Peak contrast

$$\Delta T_{peak} = \frac{Q}{\rho_1 c_1} \frac{2}{t_o \left(1+a+r+\sqrt{(1+a+r)^2 - 4ar}\right)} \cdot \left[\frac{1+a+r-\sqrt{(1+a+r)^2 - 4ar}}{1+a+r+\sqrt{(1+a+r)^2 - 4ar}} \right]^{\frac{1+a+r-\sqrt{(1+a+r)^2-4ar}}{2\sqrt{(1+a+r)^2-4ar}}}$$

Time to peak contrast

$$t_{peak} = \frac{\rho_1 c_1}{h} \frac{t_o}{\sqrt{(1+a+r)^2 - 4ar}} \ln\left(\frac{1+a+r+\sqrt{(1+a+r)^2 - 4ar}}{1+a+r-\sqrt{(1+a+r)^2 - 4ar}} \right)$$

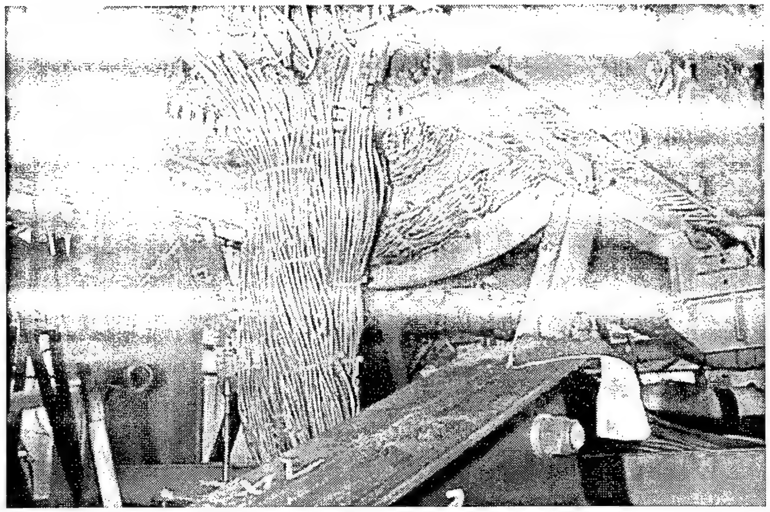
Fiber Sensors

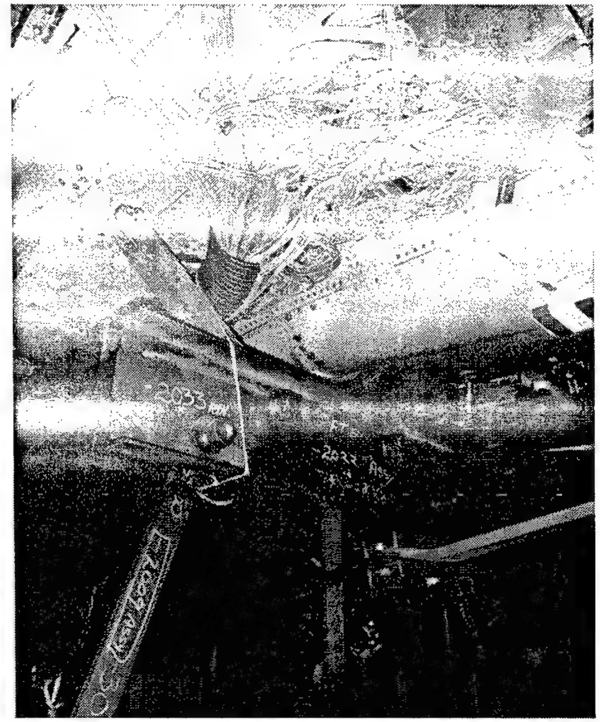
Fiber Sensors are Enabling

- Smart skins
- Smart patches
- Smart Materials
- Functional Materials (ex. Conformal antennas)
- Chemical and Biological detection in paints
- Designs for Inspection and LO materials: New and advanced structures and materials make NDI inspections very difficult
- Flight change due to combat or system damage
- Testing and Validation of structures and components
- Real-time in-flight testing and validation
- Waste Monitoring

Present System Limitations

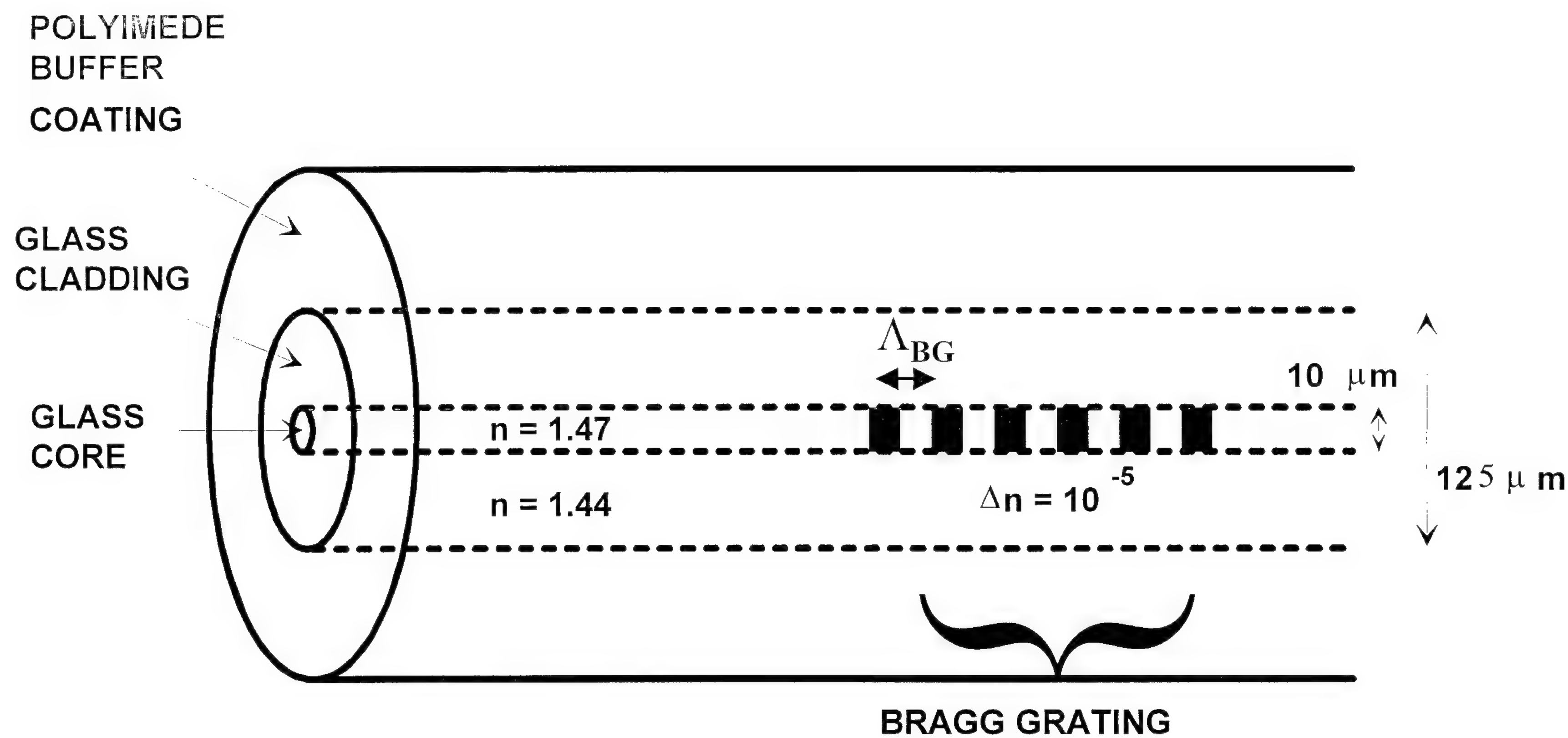
F-18 E/F Full Scale Fatigue Test





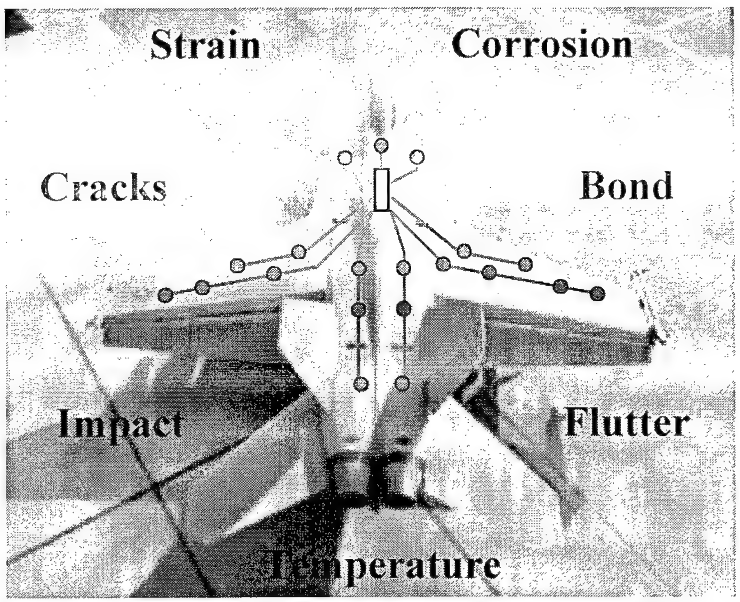
Wiring for strain sensor instrumentation during a full scale fatigue test of F-18 aircraft. Every sensor requires a minimum of two electrical leads. Each sensor requires a calibration file. Special care has to be taken to avoid EMI.

Optical Fiber Bragg Grating



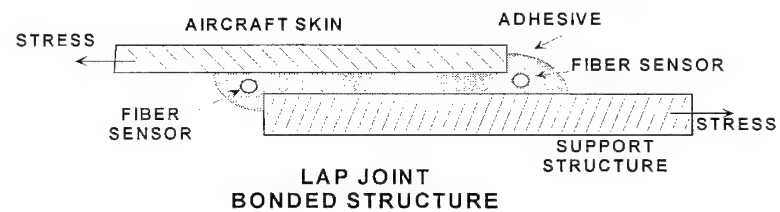
Health Monitoring System

Health Monitoring System

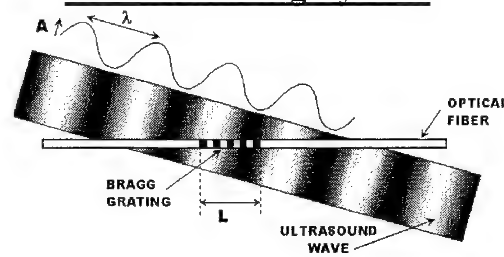


Strain/Temperature Monitoring System

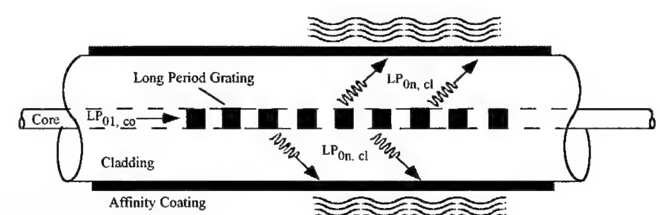
Bondline Monitoring System



AE Monitoring System

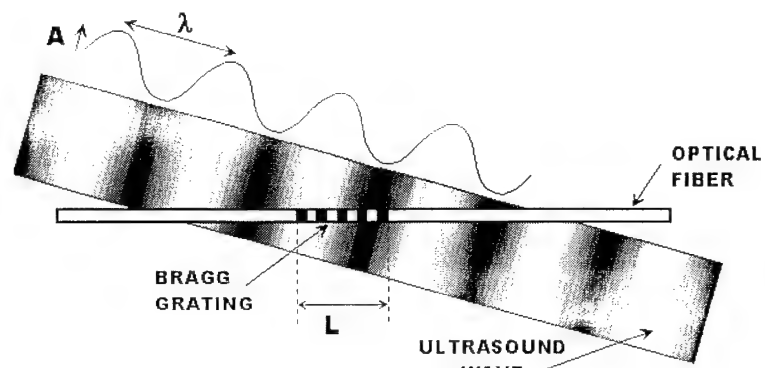


Corrosion Monitoring System

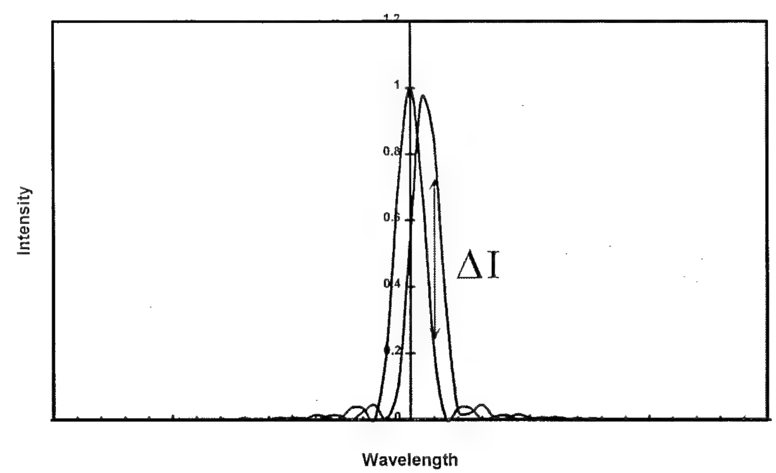


AE Sensitivity

- Determine Acoustic Emission sensitivity of Bragg Gratings
- Determine methods to enhance AE sensitivity of the sensors
- Study and optimize different demodulation schemes
- Evaluate different data acquisition, analysis and storage
- Simultaneously monitor strains, temperature, AE

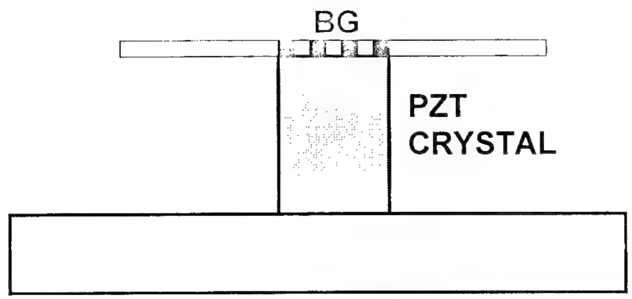


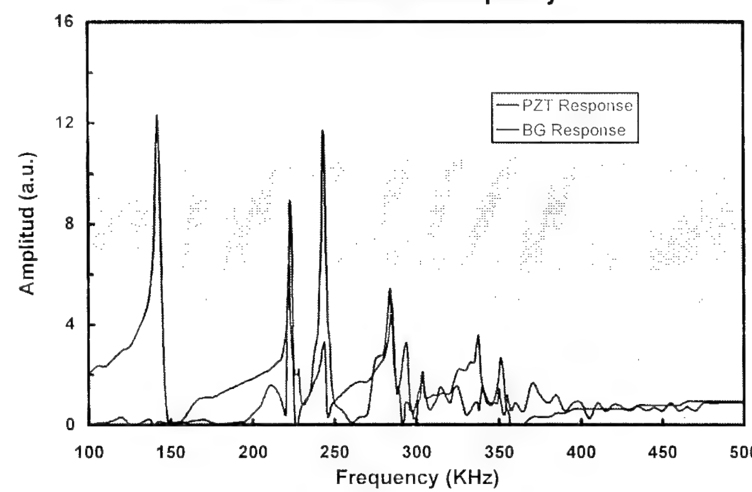
Bragg Reflection

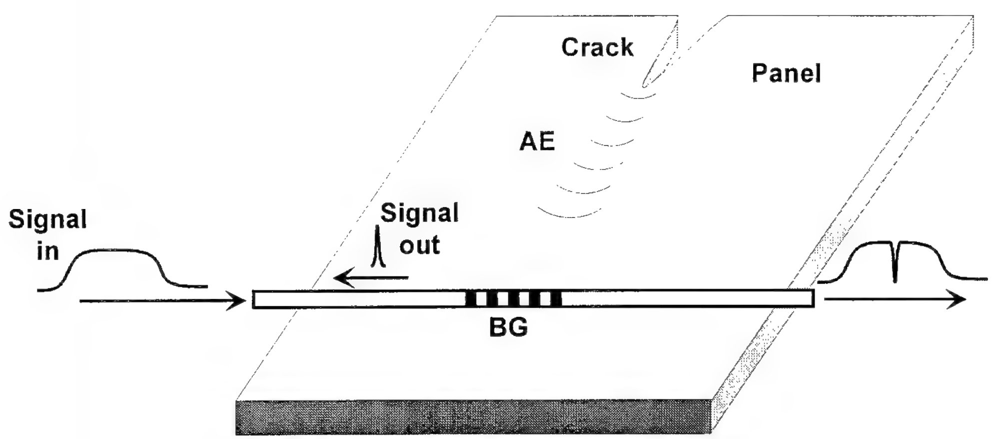


$$\Delta I \cong 2n_p \cdot I \cdot J_1(\lambda \cdot \frac{A}{\Lambda_{oB}^2}) \cdot \sin(k \cdot \frac{L}{2}) \cdot \sin(\omega \cdot t)$$

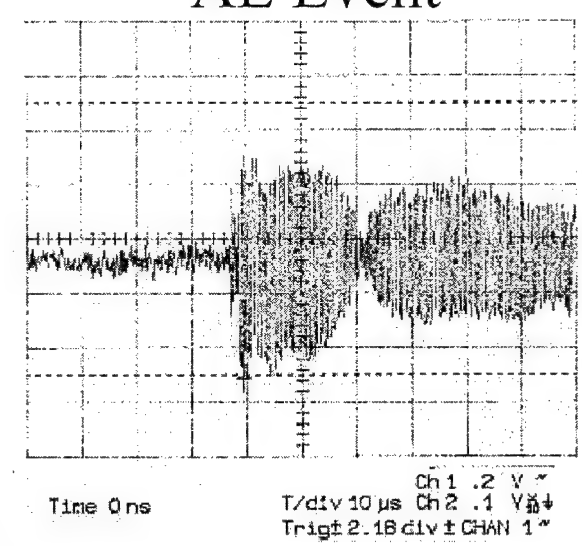
AE Sensitivity







AE Event



- Acoustic Emission event detected with a single fiber-optic Bragg grating

SERDP

Innovative Nondestructive Evaluation (NDE) Technologies for the Inspection of Cracking & Corrosion Under Coatings PP-1134

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Carderock Division
Metals Department
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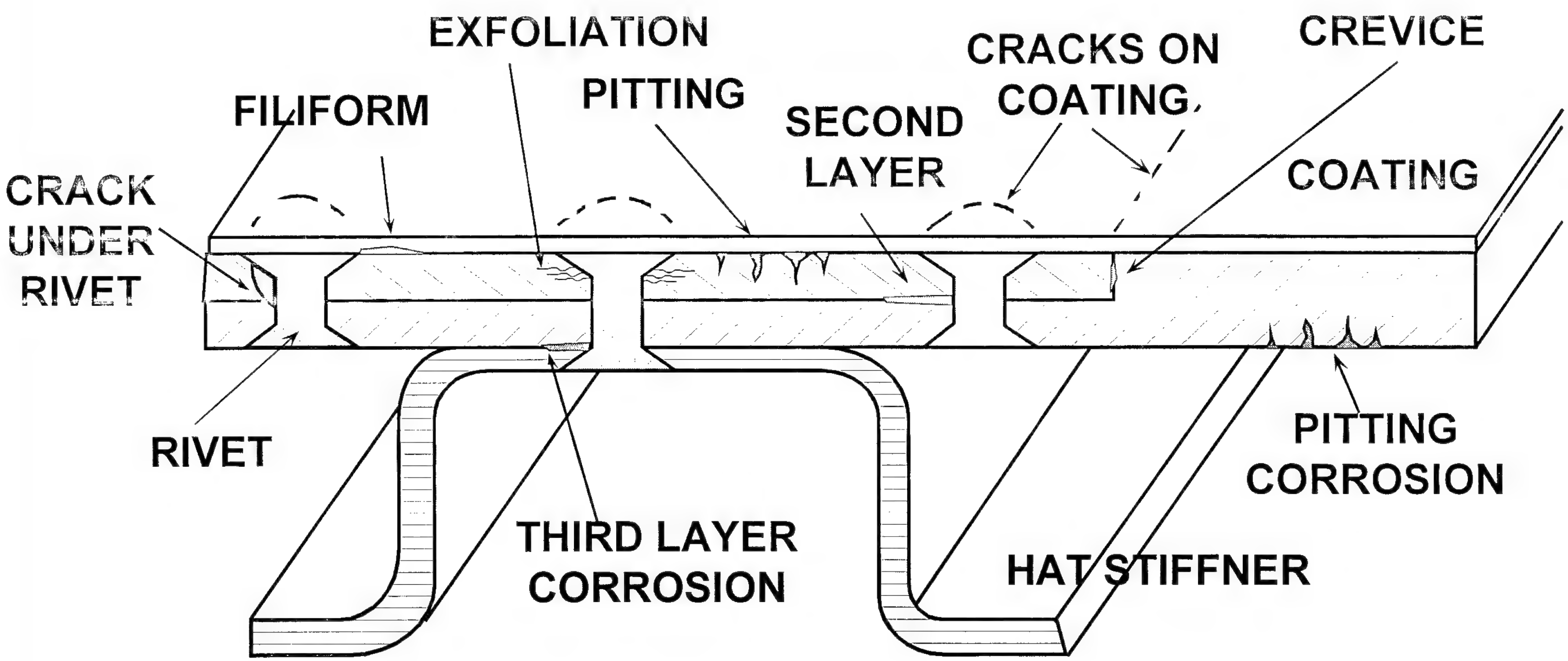
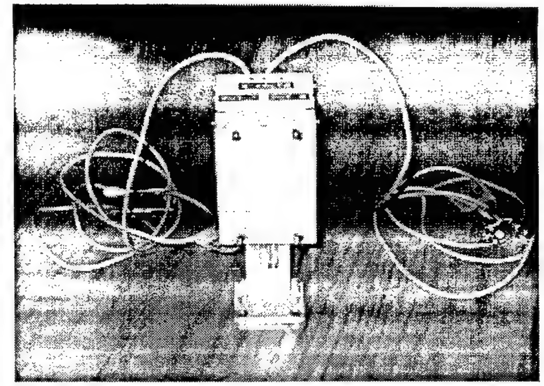
Typical Aircraft Corrosion & Crack Scenarios

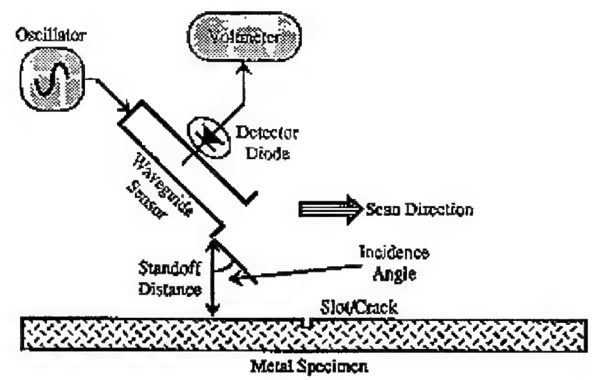


Microwave Technology

- Measure material dielectric properties
- Modify the current CSU microwave NDE model to include the effects of a coating and capability to identify corrosion sites and cracks within one instrument
- Design and prototype hand-held instruments
- Conduct lab & field trial evaluations
- Refine design



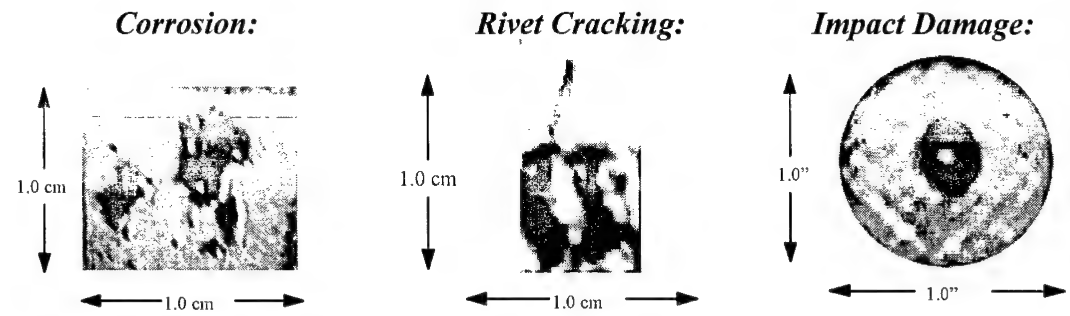
Pre-prototype 10 GHz Shipboard CUP Detection System

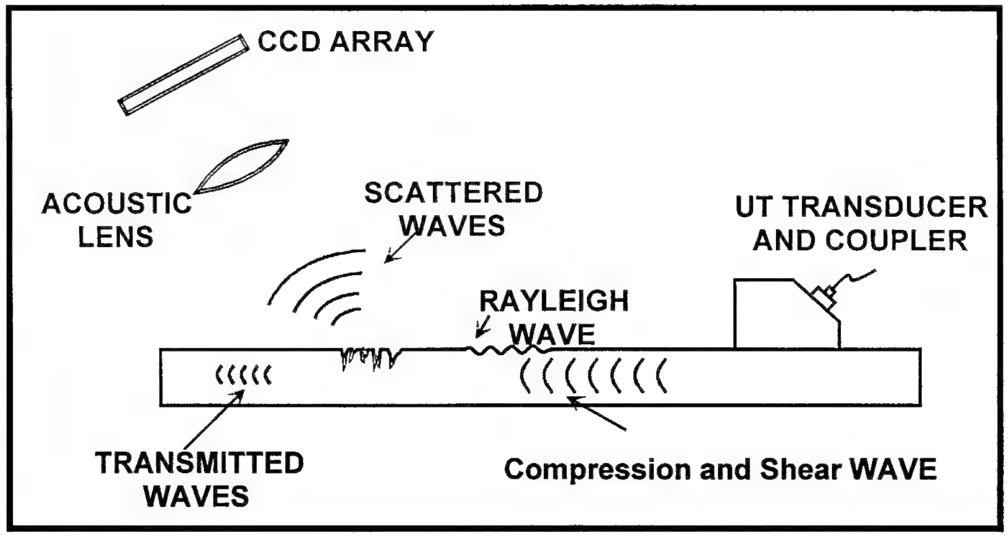


Incident Angle Tuning for Crack Defect Detection

Ultrasound Imaging

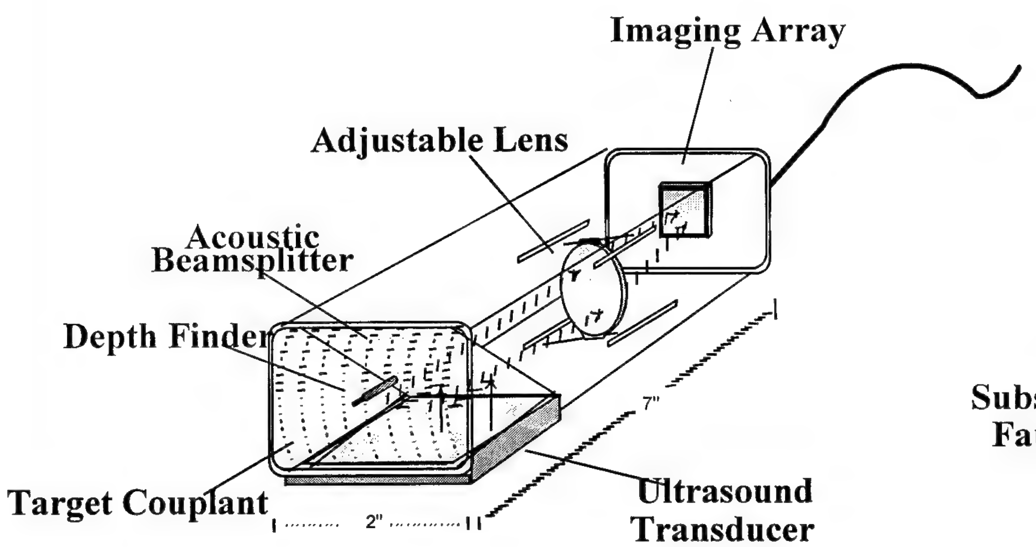
- **Study/model interaction between ultrasonic field and corrosion sites and cracks**
  - Through Transmission
  - Shear Wave
  - Scattering vs angle
  - Guided mode scattering
  - Evaluate utility of Lamb and Rayleigh waves
- **Optimize hardware**
- **Conduct lab & field trial evaluations**

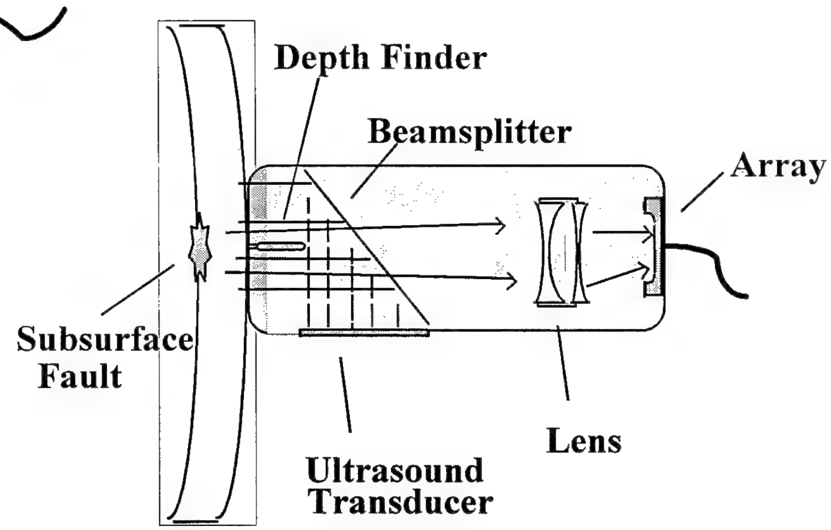


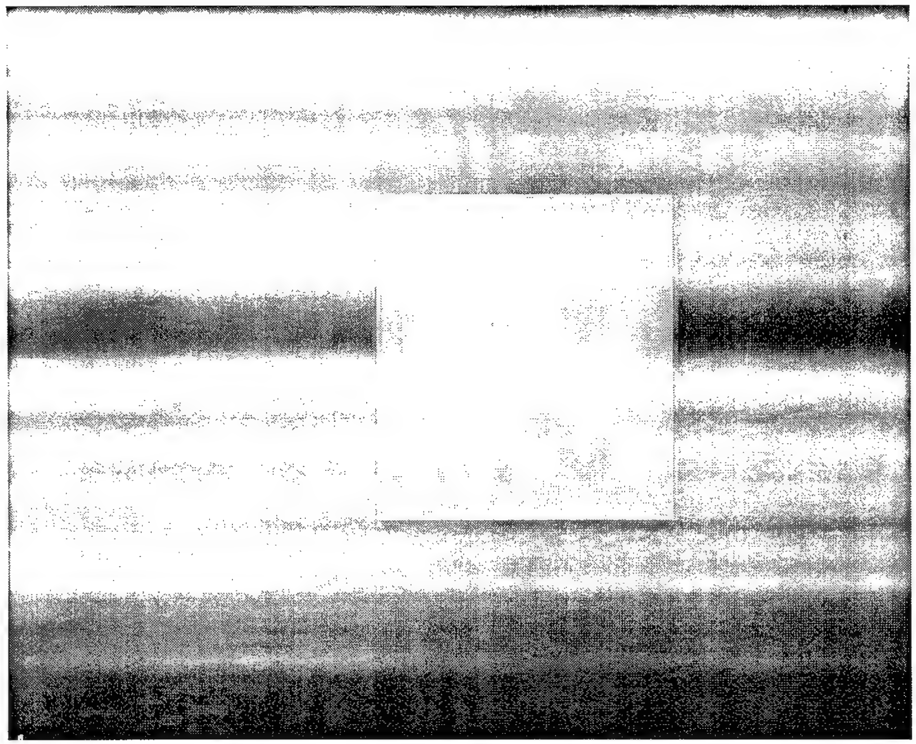


UT Imaging Concept

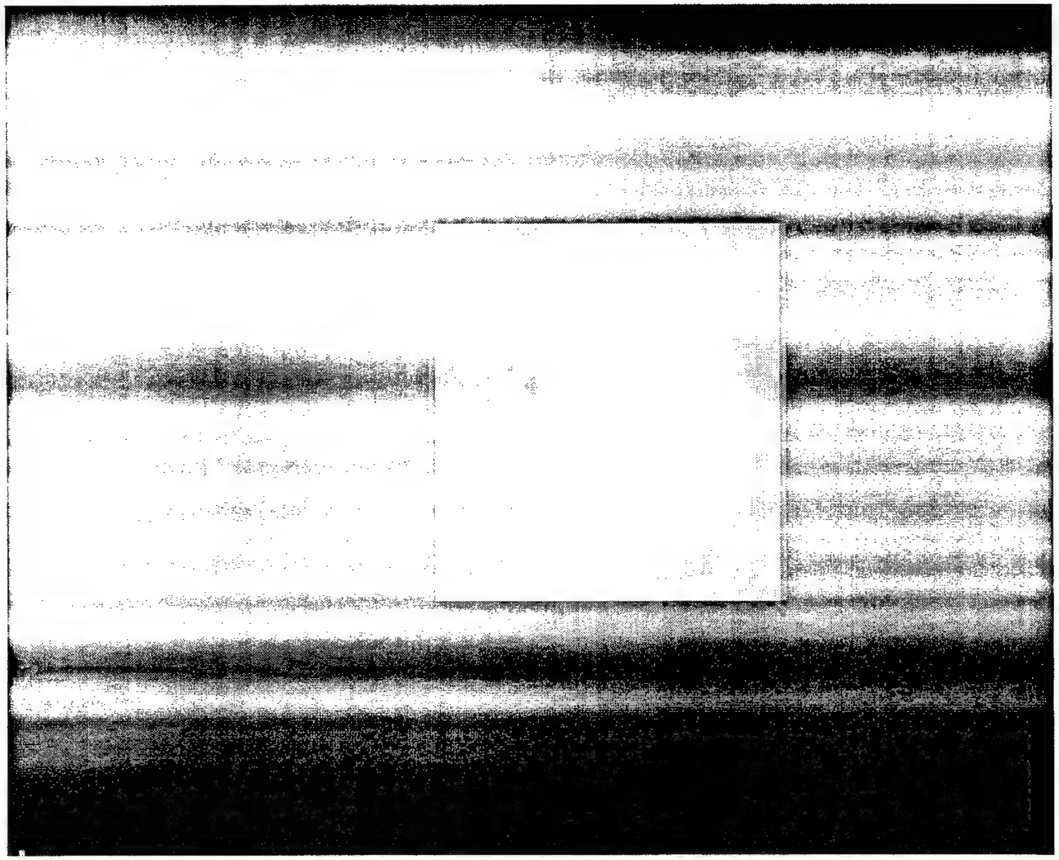
Liquid Filled Sound Wave Imaging Probe:





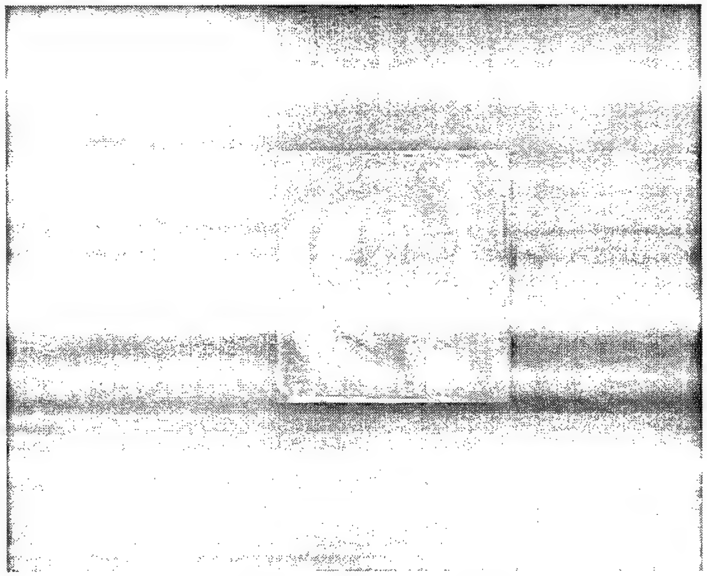


Exfoliation corrosion around rivets inspected real time using Ultrasound.



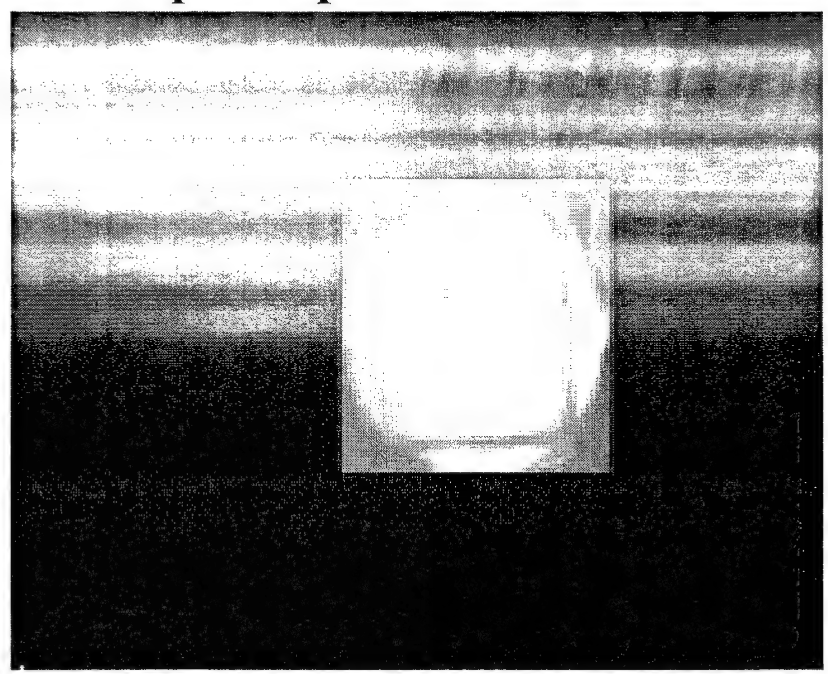
Inspection of a composite panel with built in imperfections using Ultrasound Imaging

JPEG Data

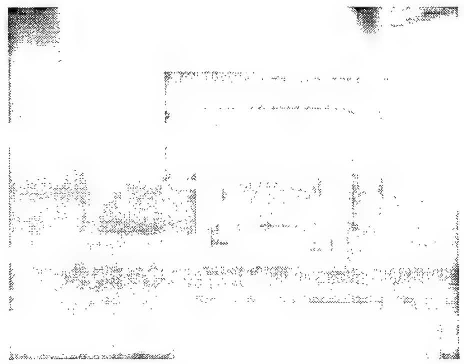


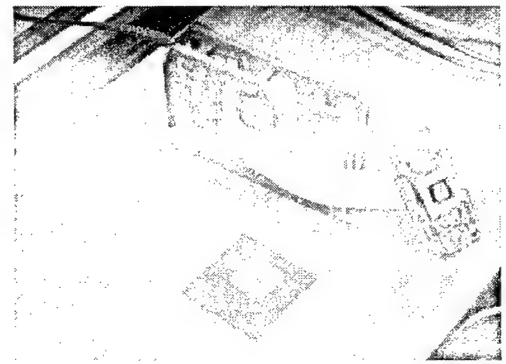
A Normal quarter in the water tank shows that the Sound Imager can detect changes in surface contour.

Inspection of damaged composite panel



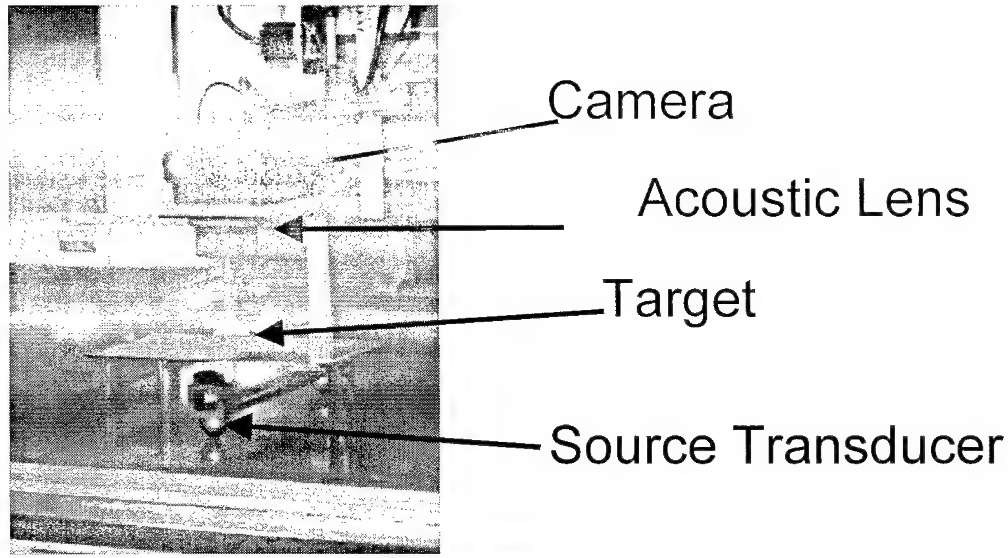
Novel Ultrasound Imaging Technique

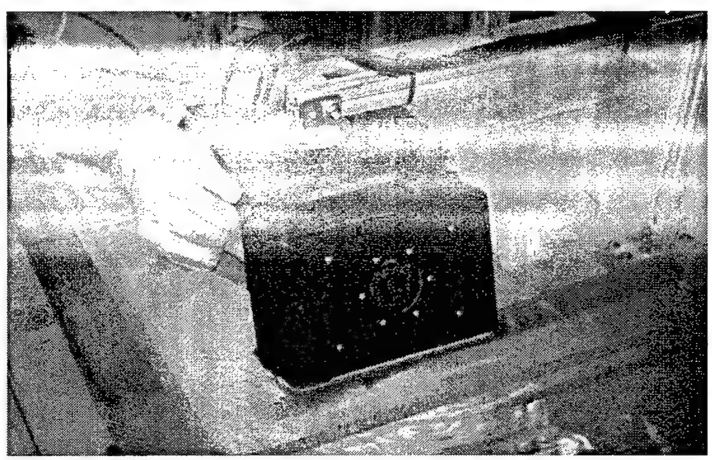




- ➔ *Uses 128 x 128 sensor array of PVDF ultrasound sensitive elements*
- ➔ *PVDF responds to ultrasound over broad range of frequencies*
- ➔ *Readout method is microelectronic CCD multiplexer*

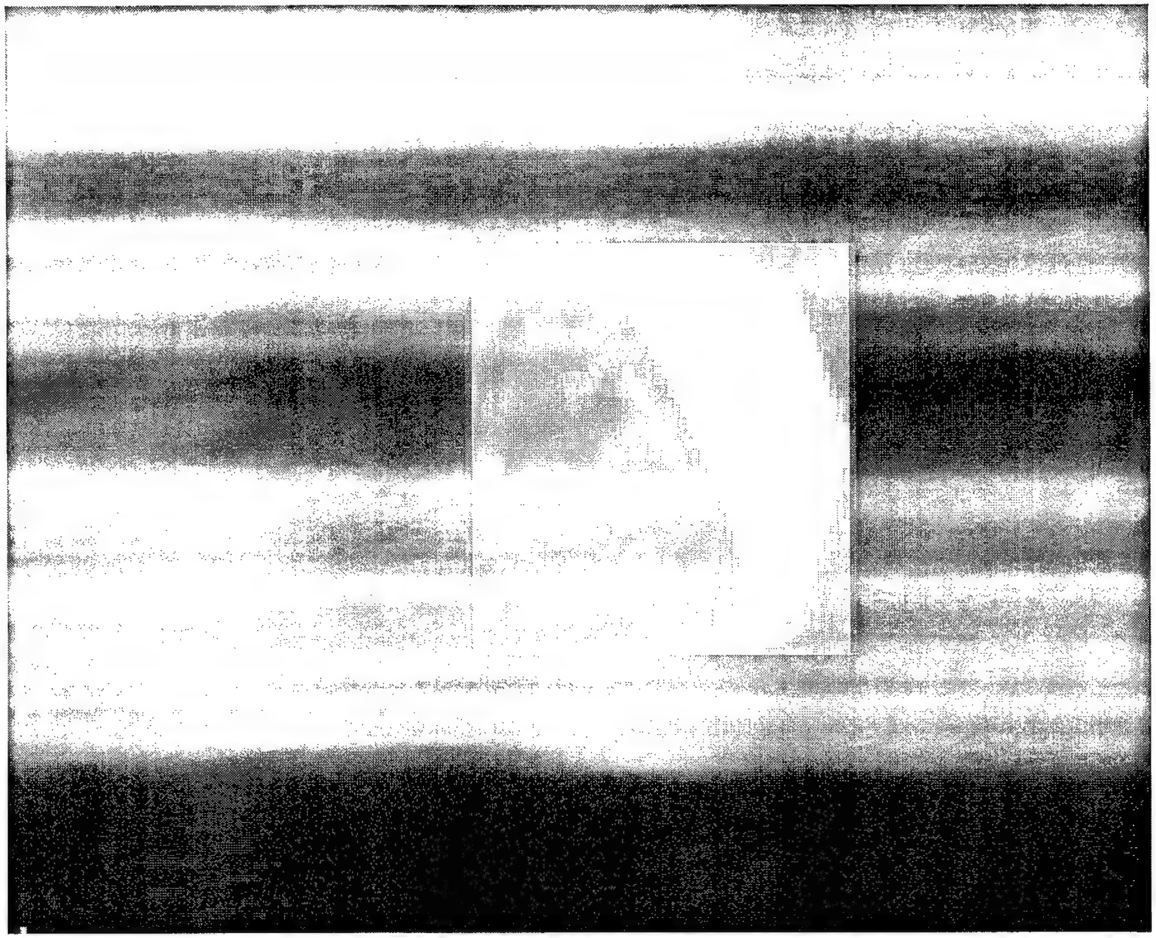
Immersion System





Camera Enclosure

Medical



http://www.imperiuminc.com/

Heat Damage of Composites

Problem

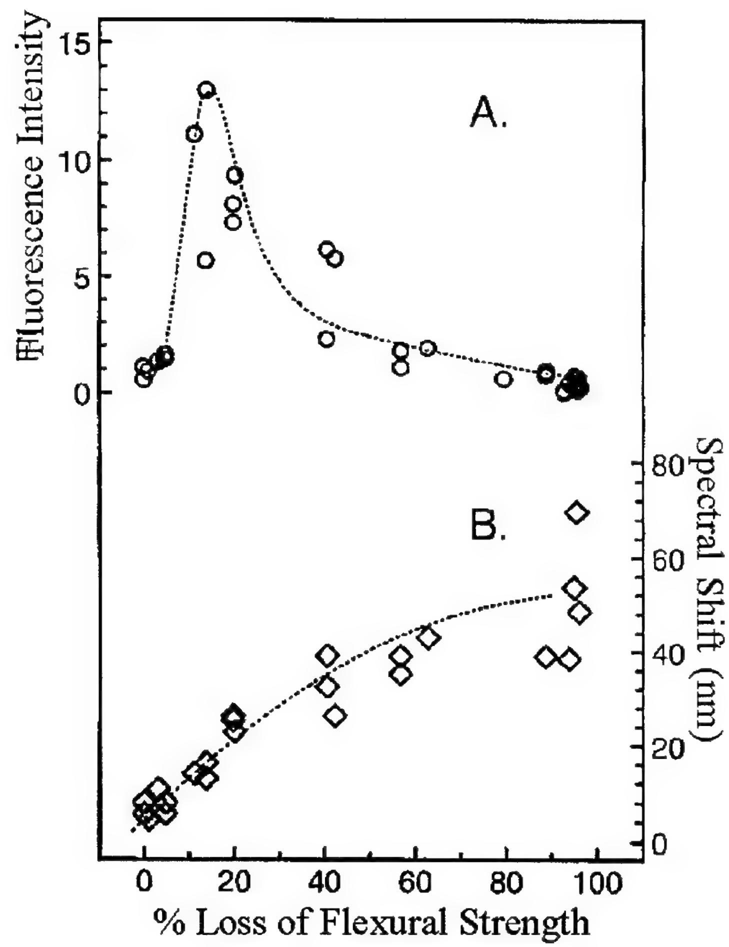
Mechanical test data shows that many organic matrix composite materials can loose up to 70% of their interlaminar shear strength do to chemical changes resulting from heat exposure. Conventional NDE methods cannot detect this damage because they are meant to find mechanical damage such as cracks and material loss

Solution

Experiments have shown that the fluorescent spectrum of the material changes as a result of chemical changes that take place in the materials when exposed to heat. This change in the fluorescence spectrum can be used as a measurement of the level of heat damage in the material

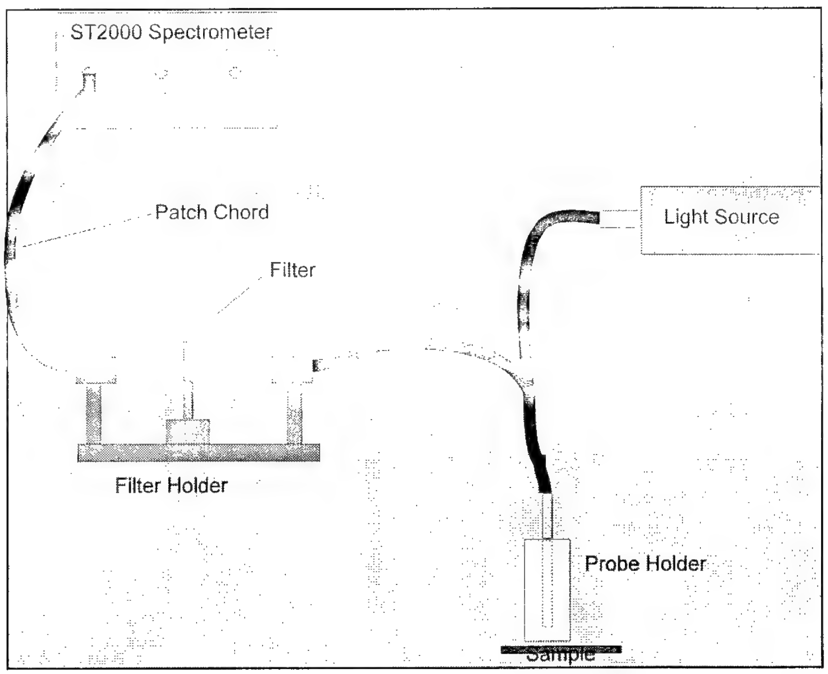
LIF Concept

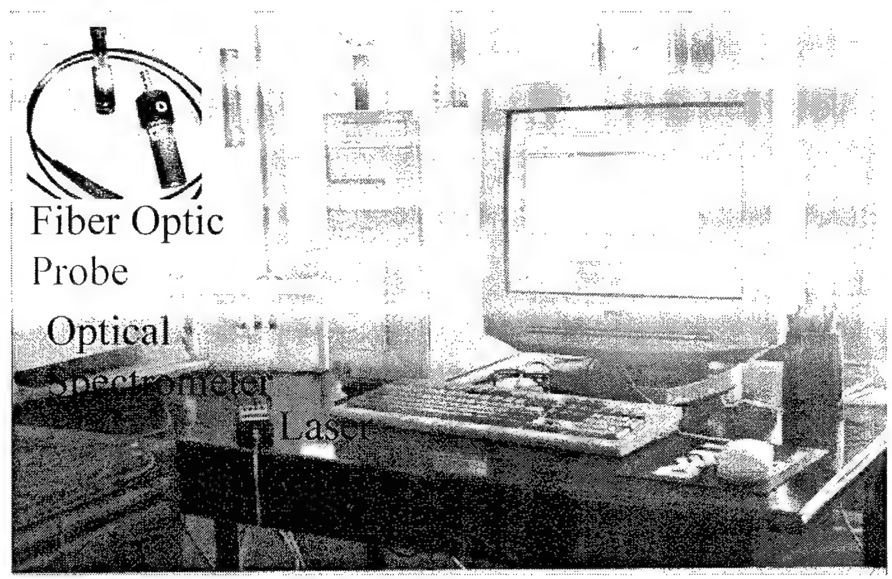
- The composite is illuminated using a laser
- The laser light excites electrons to higher energy states
- When the electrons return to their natural state, light is emitted at a longer wavelength (fluorescence)
- The spectrum of the fluoresced light is extremely sensitive to variations in material properties
- Previous work has demonstrated that the fluorescent spectrum changes as organic matrix composite materials are subjected to heat



Portable LIF Measurement Concept

- The portable LIF measurement concept is identical to that of the imaging system except the measurements are made at a single point
- A small laser is used in conjunction with a fiber optic emitting and receiving probe to illuminate the surface and gather the fluoresced light
- An optical spectrum analyzer is used to determine the wavelength at which the peak fluorescence occurs





Portable LIF System

Future Work

<u>Work planned during the remainder of 1999</u>

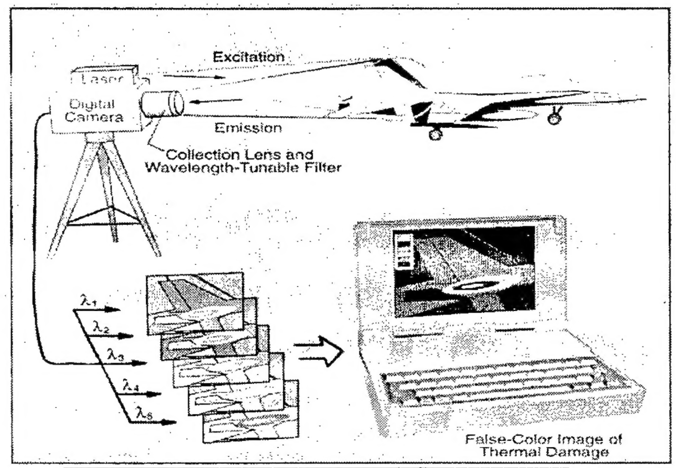
- **Optimize photon collection efficiency**
- **Collect data on a variety of samples**
- **Compare portable spectrum data with that from the imaging system**

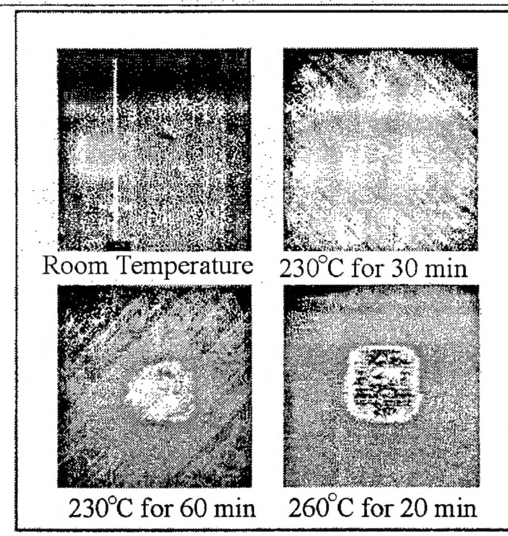
<u>Work planned in 2000</u>

- **Develop software algorithms filter data and identify peak location**
- **Convert system to a laptop-based configuration**
- **Correlate structural test data and spectrometer data**
- **Develop software algorithms to present data in a user friendly format**

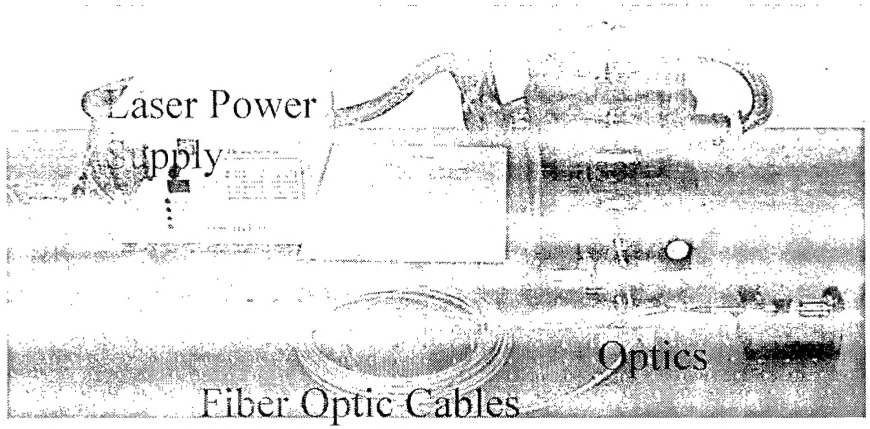
LIF Imaging Concept

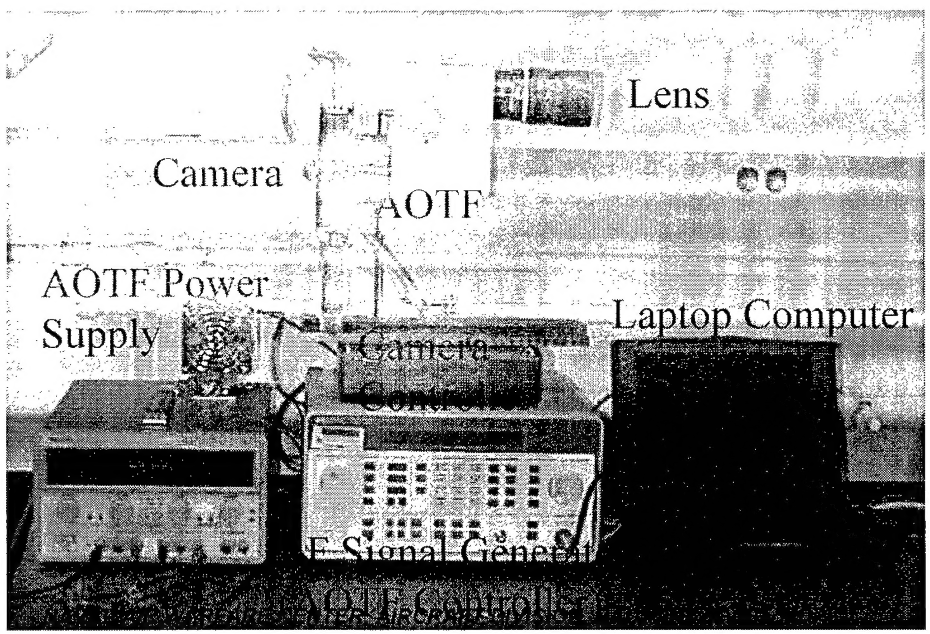
- Using filters and a digital camera the fluorescent light can be captured and false colored images can be created
- Previous work demonstrated the feasibility of creating intensity-based images within a narrow (30nm) spectrum
- Current work involves analyzing the entire fluorescent spectrum and creating images based on the wavelength at which peak fluorescence occurs
- Spectrum analysis is accomplished using an acousto-optical tunable filter





LIF Imaging System Configuration





LIF Imaging System Status

- AOTF functional and operation successfully demonstrated
- Laser illumination successfully demonstrated
- Computer control software module developed for the AOTF
- System fully integrated and demonstration of imaging at different wavelengths completed

LIF Imaging System

Future Work

Work planned during the remainder of 1999

- Incorporate high pass filter to eliminate reflected laser light
- Optimize camera and tunable filter settings
- Collect images from a variety of heat damaged samples
- Compare results with those from the portable system

Work planned for 2000

- Optimize system configuration for portability and data collection speed and ease
- Correlate structural test data and spectrometer data
- Incorporate structurally significant damage thresholds into image data
- Develop software algorithms to facilitate easy data acquisition and present it in a user friendly format